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Numerical analysis of spherically convergent Rayleigh-Taylor experiments on the Nova laser

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Abstract
In the frame of a CEA/US DOE collaboration, convergent experiments have been done on the Nova laser. Numerical simulations with our 2D Lagrangian code FCI2 led the analysis and correctly reproduced the experimental data. From single mode 2D perturbations, ablation front Rayleigh-Taylor instability growth is computed. Moderate and high convergence ratios are addressed. The shrinking of the wavelength plays a prominent role for small convergence ratio and weakly nonlinear hydrodynamics.

1. Introduction

Radiation driven experiments have been conducted on the Nova laser at the Lawrence Livermore National Laboratory in order to study the effect of convergence on the linear and weakly nonlinear growth phase of the Rayleigh-Taylor (RT) instability at the ablation front [1, 2]. We report here the numerical analyses of two set of spherical experiments, corresponding to moderate and high convergence ratios.

2. Moderate convergence implosion

Experiments in moderate spherically convergent geometry have led to a good agreement between the simulations and the experimental data [2]. The convergence ratio, defined as the ratio of the initial external radius ot the capsule to the ablation front radius, reaches a value of 2 during the implosion process.

2.1 Experimental configuration

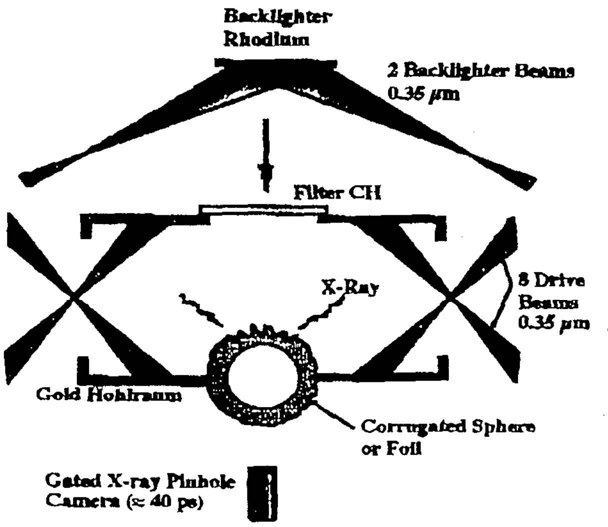

Figure 1 : *Schematic of the experimental geometry.*

The Nova experimental configuration is shown in *figure 1.* Eight of the ten Nova beams enter the hohlraum in a 2.2 ns shaped pulse ("PS26") and convert to x-rays. Total input energy is about 20 kJ.

A standard Au "scale-1" hohlraum is considered (2.75 mm long by 1.6 mm diameter) ; the capsule, 530 μm outer diameter, 42 μm CH(1.3%Ge) wall thickness with no fill presure, is mounted on a hole in the wall of the hohlraum with half the sphere interior. The interior hemisphere has had a 70 μm wavelength, 2 μm amplitude, 2D single mode axisymmetric sinusoidal perturbation imposed on it. Moderate convergence ratio close to 2 is obtained.

Two beams are used to irradiate a rhodium disk to create an x-ray backlighting source, and a fast x-ray framing camera images the sphere. Time sequences of raw images are shown in reference [1].

2.2 Numerical investigation

Simulating the experimental x-ray radiographs was a multistep process.The average drive temperature is obtained via a view factor code. It peaks at 200 eV and is in good agreement with Dante measurements.

Then we used the 2D radiation hydrodynamics code FCI2 to simulate the capsule implosion and the subsequent perturbation development due to the RT instability. Check of the gross hydrodynamics is realized by numerically reproducing the experimental wavelength time-evolution.

Finally, we used a post-processor code to simulate radiographs, which are Fourier analyzed in the same way as the experimental images. Measured and simulated growth factors in optical depth (GF_τ) are plotted in *figure 2*, both for the fundamental mode and its second harmonic. The accordance is fairly satisfactory. At the same time, the spatial growth factor GF_z localized at the ablation front, departs from purely linear regime (ie, exponential growth), but shows no evidence of saturation (see *figure 2*).

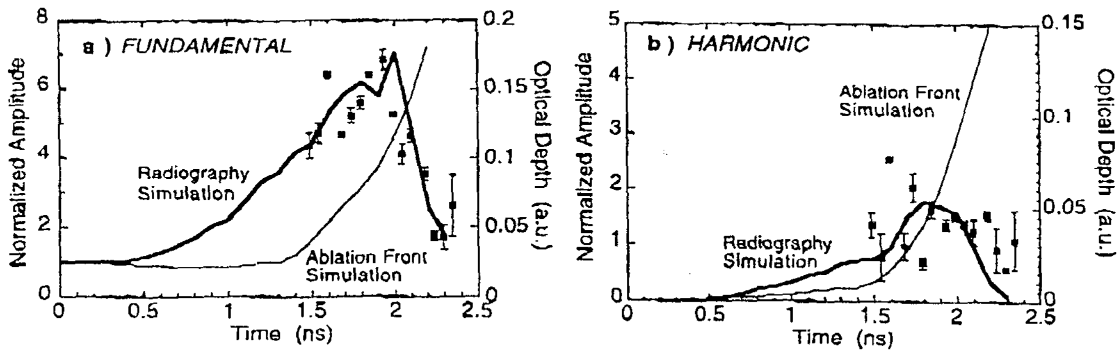

Figure 2 : *Measured (dots) and simulated (thick curves) RT growth factor are plotted, respectively in a) and b), for the fundamental and its second harmonic. Thin curves represent the spatial growth factor at the ablation front extracted from FCI2 simulation.*

The apparent saturation for GF_τ results from the combined effect of the decompression, the change in the opacity coefficient, the finite instrument spatial resolution and two additional effects due to the convergent geometry, which are the time dependent decrease of the instrument modulation transfert function as the wavelength decreases, and the deviation of the spikes from the diagnostic line of sight.

2.3 Comparison between planar and convergent cases

Identical experiments were conducted using 50 µm thick planar foils of CH(2%Br) in place of the hemispheres. It appears that the convergent case grows more quickly and enters in the nonlinear regime sooner, but direct comparisons of the planar and convergent case are difficult as shock breakout on the rear side and acceleration phase of the ablation front don't occur at the same time.

From the simulations, we consider the evolution of the perturbation amplitudes versus $\sqrt{s}$, where s is the distance accelerated. This quantity is directly extracted from the FCI2 simulations, as the distance traveled by the ablation front since the time when the acceleration stage begins. To take into account the reduction of the wavelength λ during the compression, we plotted the growth rate versus $\sqrt{s/\lambda}$. We observe in *figure 3* that it gives rougly the same result for the planar and the convergent case. Hence, we conclude that for small convergence ratios and weakly nonlinear hydrodynamics, dominant effect of convergence is simply the shrinking of the wavelength.

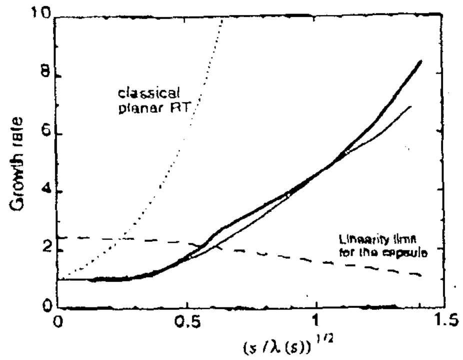

Figure 3 : *Simulated growth rate versus $\sqrt{s/\lambda}$, where s is the distance accelerated, for the planar (thin line) and the spherical (thick line) cases. Classical RT growth rate and linearity threshold for the capsule (when the perturbation amlpitude equals 10% of the wavelength) are in dashed lines.*

3. High convergence implosion

More recent experiments have addressed convergence ratios up to 4, by considering larger capsules and larger hohlraum. To avoid a too important decrease of the drive temperature, the experiments used a ratio of the capsule radius to the hohlraum radius equal to 0.33. This relative high value for this ratio led to a significative capsule pressure distorsion. Present numerical analysis investigates the observed experimental distorsions obtained by S.G. Glendinning [Communication at the 29th Anomalous Absorption Conference, Monterey, 1999].

3.1 Experimental configuration

The experimental configuration is very similar to the one described in §2.1. We dealt with a longer pulse : a 4.5 ns shaped pulse ("PS35"). The experiments have been performed considering a "scale-1.5" hohlraum (3.40 mm long by 2.4 mm diameter) ; the capsule, 800 µm outer diameter, 42 µm CH(1.3%Ge) wall thickness, is located in the center of the hohlraum. One hemisphere had a 2D single mode axisymmetric Legendre polynomial perturbation (mode 24 or 32) with a 0.5 µm amplitude imposed on it.

3.2 Investigation of the implosion symmetry

Numerical analysis is realized step by step in the way developped in §2.2. As the same laser energy enters a larger hohlraum in a longer pulse, the drive temperature is significantly lower and peaks at 130 eV.

A 2D simulation of the whole geometry, gold hohlraum and unperturbed capsule, is performed with the FCI2 code. From the simulation of radiographs, we perform a Legendre analysis of the external spatial contour of the capsule, and make a comparison between numerical and experimental data. Numerical simulations are not yet completed, but up to now the agreement on the radius as a function of time is correct (see *figure 4*) ; a time shift should be introduced for the experimental data in order to take into account the shot-to-shot drive variations. Experimental data exhibit large fluctuations for P_2 and P_4 distorsions but general trend is in accordance. Late time simulations are going on.

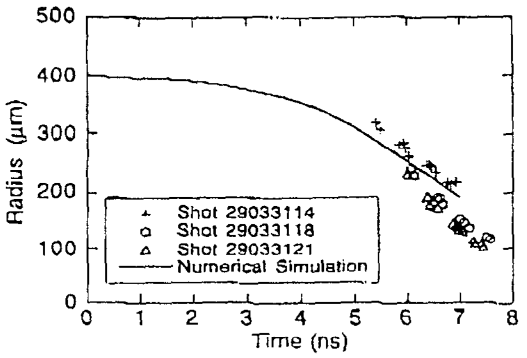

Figure 4 : *Time evolution of the outer radius obtained by analysis of the capsule radiograph in the experiments (dots) and in the FCI2 simulation (plain line).*

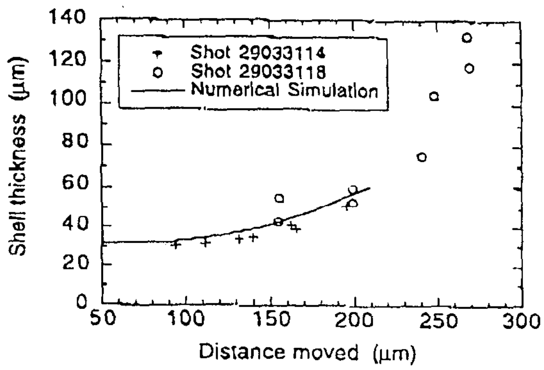

Figure 5 : *Evolution of the capsule thickness versus the accelerated distance in the experiments (dots) and in the FCI2 simulation (plain line).*

The thickening of the capsule versus time extracted from experimental radiographs exhibits an unsteady evolution, and specifically a fast evolution when the capsule radius becomes smaller than half the initial radius. This should induce an increase of convergence effects. Although our simulations are not finished, we have plotted a numerical thickness obtained by taking the FWHM of the denser part of the simulated radiographs. It is compared against experimental data in *figure 5*, and plotted versus the distance moved by the external dense radius (close to the ablation front) in order to avoid temporal shift due to laser history variations. The accordance between experimental and numerical data is a good way to check that the simulations are relevant.

We apply an analytic view factor model developped by S. Laffite [Unpublished CEA Report and Communication at the APS Plasma, Seattle, 1999]. It provides the illumination pattern for a cylindrical hohlraum geometry. The flux asymmetries at the hohlraum wall or at the capsule surface is decomposed into Legendre polynomials P_l. The polynomials P_2, P_4, P_6,P_8 are quantified, while odd orders are zero as asymmetry about the hohlraum midplane is considered.

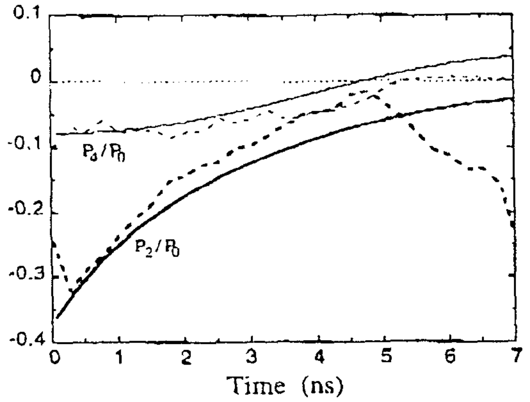

Figure 6 : *Time dependence of P_2/P_0 and P_4/P_0 incident flux assymetry on the capsule calculated by the analytic model (solid lines) and by FCI2 simulations (dashed lines).*

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This model includes laser beams pointing via the widths of the illumination rings, the effects of hohlraum wall motion, the time-varying wall albedo. The results of the model, and specially the time-dependent asymmetries of the incident flux on the capsule P_2/P_0 and P_4/P_0, compare notably well with the 2D FCI2 simulations (see *figure 6*) ; at late times, the nominal incident flux gets small.

3. Conclusions and prospects

Experiments have been done on the Nova laser to investigate the effects of convergence on Rayleigh-Taylor growth. Reasonable agreement is found between the simulated and measured data. For a moderate convergence ratio case, close to 2, the dominant effect of convergence can be expressed by the shrinking of the wavelength. For high convergence ratio, up to 4, numerical analysis is not yet completed ; experimental data seem to indicate that convergence effects are important when the radius becomes smaller that half its initial value, but it has to be confirmed by numerical simulations. When the distorsions of symmetry will have been fully analyzed and understood, perturbation growth will be addressed.

REFERENCES

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